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Contents

i Executive summary

The NAFO/ICES *Pandalus* Assessment Group (NIPAG), met to assess the *Pandalus* stock in divisions 3.a and 4.a east. The objective was to assess stock status and to draft advice according to the ICES MSY approach and the current EU and Norway Long-term Management Strategy (LTMS). The LTMS requires ICES to provide both an update in-year TAC advice for 2022 and an initial TAC advice for the first two quarters of 2023.

A length-based Stock Synthesis (SS3) statistical framework was used to assess the status of the stock based on updated input data (commercial catches for 2021 and survey catches from January 2022). The assessment model and reference points were updated during the 2022 benchmark (WKPRAWN 2022) and now contains hermaphroditic parameters, two areas, and six fleets. The model is also now fit using a novel ensemble approach whereby three different natural mortality rates are considered. The assessment demonstrated that the fishing pressure on the stock is below FMSY and that spawning–stock size is below MSY $B_{trigger}$ and B_{pa} but above B_{lim}.

In accordance with the ICES MSY approach and new reference points NIPAG advises that catches in 2022 should be no more than 7712 tonnes, and that catches for the first two quarters of 2023 should be no more than 5882 tonnes. This corresponds to a 29% reduction of the initial catch advice for 2022 (10 890 tonnes). This change is partly explained by the realized catches in 2021 being higher than the advised catches (7484 tonnes realized, compared to 7166 tonnes advised). The preliminary advised catch for 2023 is 51% larger than the advised catch for 2022 mainly because the 2021- and 2022-year classes are estimated to be higher than the 2020-year class.

SS3 model diagnostics of the assessment did not indicate any issues with model fit. There is a positive retrospective bias in SSB and negative retrospective bias in F and recruitment, but these are all within the acceptable range (Mohn's Rho threshold values) of requiring no action.

ii Expert group information

Expert group name	Joint NAFO\ICES *Pandalus* Assessment Working Group (NIPAG)
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chairs	Ole Ritzau Eigaard, Denmark
	Mark Simpson, Canada
Meeting venue and dates	28 February – 2 March 2022, Online meeting (14 participants)

1 Northern shrimp (*Pandalus borealis*) in the Skagerrak and Norwegian Deep (ICES Subdivision 27.3a.20 and the eastern part of Division 27.4a

Background documentation is found in NAFO SCR Docs. 13/068; 16/056; 22/001 and in the ICES Stock Annex.

1.1 Introduction

Shrimp in ICES Division 27.3a (Skagerrak and Kattegat) and the eastern part of Division 27.4a (Norwegian Deep) are assessed as one stock and are exploited by Norway, Denmark, and Sweden. Shrimp fisheries expanded significantly in the early 1960s. By 1970, the landings had reached 5000 t and in 1981 they exceeded 10 000 t.

Since 1992, the shrimp fishery has been regulated by a TAC (Figure 1.1, Table 1.1). The overall TAC is shared according to historical landings, giving Norway 59%, Denmark 27%, and Sweden 14% between 2011 and 2022. During a recent benchmark in January 2022, an updated assessment model (in Stock Synthesis) was agreed upon (ICES, 2022). The updated assessment model contains hermaphroditic parameters, two areas, and six fleets (see below). The new model is also fit using a novel ensemble approach whereby three different SS3 models, each with a different age-varying natural mortality rate, are run and combined to provide advice.

The shrimp fishery is also regulated by a minimum mesh size (35 mm stretched), and by restrictions in the amount of landed bycatch. Sorting grids are mandatory in the whole area (see below). In 2009, an EU ban on high-grading was implemented and since 2016, the EU landing obligation applies for *Pandalus* in 27.3a and 27.4a. Norway has had a discard ban for many years.

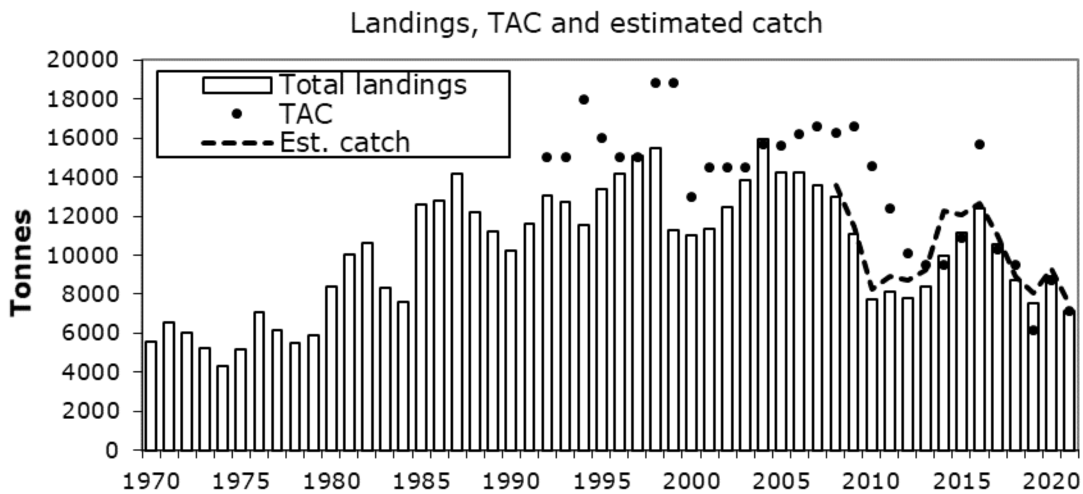

Figure 1.1. Northern shrimp in Skagerrak and Norwegian Deep: TAC, total landings by all fleets, and total estimated catch including estimated Swedish discards for 2008–2021, estimated Norwegian discards for 2009-2021, and estimated Danish discards for 2013–2021.

Table 1.1. Northern shrimp in Skagerrak and Norwegian deep: TACs, landings, estimated discards, and catches (t). The boiled portion of the landings have been corrected for loss of weight due to boiling.

Year	2011	2012	2013	2014	2015	2016[1]	2017	2018	2019	2020	2021
Advised TAC[2]	8800	*	5800	6000	10900	13721	10316	8571	6163	8736	7166
Agreed TAC	12380	10115	9500	9500	10900	15696	10316	8900	6163	8736	7166
Denmark landings	1593	1456	2027	2431	2690	1995	2158	1867	2048	2300	1687
Norway landings	4800	4853	5179	6122	6810	8305	6778	5492	4414	5348	4561
Sweden landings	1768	1520	1190	1398	1645	2087	1635	1375	1107	1289	925
Total land-ings	8161	7829	8396	9951	11145	12387	10571	8734	7569	8937	7173
Est. Swedish discards	504	671	265	572	325	108	104	86	211	242	156
Est. Norw. discards	227	248	405	1191	418	105	114	115	178	82	99
Est. Danish[3] discards	-	-	185	526	202	35	206	12	83	60	57
Total catch	8892	8748	9251	12240	12090	12635	10994	8946	8041	9320	7484

[1] Advised and agreed TACs from October 2015 were changed in March 2016 following the benchmark assessment.

[2] From 2014, TAC advice has been given for catches.

[3] DK discard estimates in weight are available from 2009-2012 but were not used in the assessment because of a shift in sampling procedure and data resolution in 2013.

The Danish and Norwegian fleets have undergone major restructuring over the last 25 years. In Denmark, the number of vessels targeting shrimp has decreased from 191 in 1987 to only eight in 2021. The efficiency of the fleet has increased due to the introduction of twin trawls and increased trawl size.

In Norway, the number of vessels participating in the shrimp fishery has decreased from 423 in 1995 to 177 in 2021. Twin trawls were introduced in 2002, and in 2011–2021 were used by more than half of the Norwegian trawlers longer than 15 meters.

The Swedish specialized shrimp fleet (landings of shrimp exceeding 10 t per year) has decreased from more than 60 vessels in 1995–1997 to below 30 in 2018–2021. There has not been any major change in single trawl size or design, but during the last ten years, the landings of the twin trawlers have increased from 7 to over 60% of the total Swedish *Pandalus* landings.

Landings and discards. Total landings have varied between 7000 and 16 000 t during the last 30 years. In the Swedish and Norwegian fisheries, 50–70% of catches (large shrimp) are boiled at sea, and almost all catches are landed in homeports. Danish vessels boil approximately 35% of shrimp onboard and land the product in Sweden to obtain a better price. The rest is landed fresh in homeports. In the total catch estimates, the boiled fraction of the landings has been raised by a factor of 1.13 to correct for weight loss caused by boiling. Total catches, estimated as the sum of landings and discards, decreased from 2008 to 2012 (to approx. 8800 t) and then increased to around 12 600 t in 2016. The last four years, catches have fluctuated between 7000 t and 9000 t (Table 1.1 and Figure 1.1).

Shrimp may be discarded to replace small and medium-sized, lower-value shrimps with larger and more profitable ones (“high-grading”). Since 2016, small shrimp <15 mm CL have been marketable, but they fetch a lower price than medium-sized shrimp. The Swedish fishery has often been constrained by the national quota, which may have resulted in high-grading. Based on onboard sampling by observers, discards in the Swedish fisheries were estimated to be between 12 and 31% of total catch for 2008–2015 (Munch-Petersen *et al.*, 2013), and Danish discards were estimated to be between 2 and 18% for 2009–2015. In 2016, due to the landing obligation, discarding decreased to 4 and 2% in Sweden and Denmark respectively. In 2021, the discard percentages were 14.5 and 3.2%, respectively. In 2017 to 2021, approximately 80% of the Swedish landings were caught with mesh sizes of at least 45 mm.

From 2009 to 2016, Norwegian discards in Skagerrak were estimated by applying the Danish discards-to-landings ratio to the Norwegian landings. Since 2017, Norwegian discards have been estimated based on data from the Norwegian Coastal Reference fleet (Hatlebrekke *et al.*, 2021). Discards in the Norwegian fisheries are estimated to be between 1.5 and 4% of total catch for 2017–2021.

Bycatch and ecosystem effects. Shrimp fisheries in the Norwegian Deep and Skagerrak have bycatches of approx. 10–25% (by weight) of commercially valuable species, which are legal to land if quotas allow (Table 1.2).

Since 1997, trawls used in Swedish national waters must be equipped with a Nordmøre grid, with a bar spacing of 19 mm, which excludes fish larger than approx. 20 cm length from the catch. Following an agreement between the EU and Norway, the Nordmøre grid was made mandatory in all shrimp fisheries in Skagerrak from 1 February 2013 (except in Norwegian national waters within the 4 nm limit where it only became mandatory in 2019). From 1 January 2015, the Nordmøre grid has also been mandatory in all shrimp fisheries in the North Sea south of 62°N. If the fish quotas allow, it is legal to use a fish retention device/collecting bag made of 120 mm square meshes at the grid’s fish outlet.

Table 1.2. Northern shrimp in Skagerrak and Norwegian Deep: Bycatch landings by the *Pandalus* fishery in 2020 (not updated with data from 2021). Combined data from Danish and Swedish logbooks and Norwegian sale slips (t).

Species	SD 3.a, grid		SD 3.a, grid+fish tunnel		SD 4.a East, grid+fish tunnel	
	Landings (t)	% of total landings	Landings (t)	% of total landings	Landings (t)	% of total landings
Pandalus	329.5	95.5	5928.0	82.3	2007.9	82.2
Norway lobster	4.6	1.3	30.6	0.4	4.5	0.2
Anglerfish	0.6	0.2	104.2	1.4	55.8	2.3
Whiting	0.0	0.0	2.3	0.0	1.8	0.1
Haddock	0.5	0.1	18.8	0.3	12.8	0.5
Hake	0.1	0.0	34.8	0.5	23.1	0.9
Ling	0.1	0.0	46.1	0.6	32.5	1.3
Saithe	1.9	0.6	617.6	8.6	196.6	8.1
Witch flounder	0.2	0.0	38.5	0.5	2.1	0.1
Norway pout	4.4	1.3	26.9	0.4	6.5	0.3
Cod	1.8	0.5	224.0	3.1	41.3	1.7
Other marketable fish	1.4	0.4	128.5	1.8	57.0	2.3

Table 1.3. Northern shrimp in Skagerrak and Norwegian Deep: Estimated indices of predator biomass (catch in t per square nautical mile) from the Norwegian shrimp survey in 2008–2022. The 2016 survey data have been omitted (see text for details).

Species														
English	**Latin**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Blue whiting	*Micromesistius poutassou*	1.21	0.27	0.62	3.30	29.03	1.88	5.25	31.18	6.38	19.68	13.04	59.02	21.99
Saithe	*Pollachius virens*	53.89	18.53	7.52	5.66	112.80	14.13	8.56	9.71	12.87	5.77	1.88	5.13	4.15
Cod	*Gadus morhua*	2.01	1.79	1.66	1.26	1.69	2.92	2.37	2.00	2.05	2.58	0.58	1.00	1.87
Roundnose grenadier	*Coryphaenoides rupestris*	19.03	10.05	4.99	4.43	1.97	2.90	1.46	1.41	2.17	2.10	3.53	1.85	3.74
Rabbit fish	*Chimaera monstrosa*	3.26	3.51	2.73	2.22	3.05	3.90	2.19	5.99	5.03	5.40	4.35	4.01	3.67
Haddock	*Melanogrammus ae-glefinus*	3.18	3.46	5.82	5.75	5.18	2.15	2.60	1.86	1.51	0.97	1.15	3.94	9.54
Redfish	*Scorpaenidae*	0.43	0.80	1.02	0.37	0.47	0.48	0.20	0.53	0.97	0.82	0.31	0.50	0.56
Velvet belly	*Etmopterus spinax*	2.42	2.52	1.47	1.59	2.67	1.91	2.51	4.19	3.85	4.34	2.92	4.19	5.21
Skates, rays	*Rajidae*	0.17	0.60	0.88	0.98	1.00	2.25	1.69	1.64	1.20	1.76	0.65	1.39	1.35
Long rough dab	*Hippoglossoides platessoides*	0.28	0.47	0.51	0.56	0.56	1.17	1.45	0.94	0.81	1.02	0.34	0.41	0.41
Hake	*Merluccius merluccius*	2.56	1.60	0.56	0.52	1.06	0.69	0.59	1.24	1.66	0.91	1.00	1.16	0.68
Angler	*Lophius piscatorius*	1.25	1.70	0.92	0.17	0.65	0.75	0.58	1.13	0.57	1.12	0.71	0.76	0.77

Species														
English	**Latin**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Witch	*Glyptocephalus cyno-glossus*	0.16	0.13	0.24	0.29	0.27	0.35	1.38	0.47	0.17	0.16	0.19	0.40	0.31
Dogfish	*Squalus acanthias*	0.14	0.11	0.21	0.60	1.02	1.00	0.36	0.42	0.45	0.43	0.26	0.32	0.42
Black-mouthed dogfish	*Galeus melastomus*	0.15	0.09	0.09	0.09	0.12	0.11	0.35	0.26	0.24	0.24	0.35	0.16	0.20
Whiting	*Merlangius merlan-gus*	3.02	2.42	3.07	1.64	2.02	3.38	1.59	2.60	4.56	5.20	2.62	4.62	5.43
Blue Ling	*Molva dypterygia*	0	0	0	0	0.01	0.01	0.03	0.01	0.03	0.02	0.25	0.08	0.05
Ling	*Molva molva*	0.79	0.64	0.24	0.17	0.22	0.32	0.63	0.90	0.99	1.09	0.41	0.27	0.32
Four-bearded rockling	*Rhinonemus cimbrius*	0.03	0.05	0.03	0.09	0.04	0.06	0.12	0.04	0.05	0.09	0.05	0.04	0.04
Cusk	*Brosme brosme*	0.05	0.13	0.29	0.04	0.10	0.05	0.19	0	0.14	0.38	0.02	0.02	0.08
Halibut	*Hippoglossus hippo-glossus*	0.09	0.20	0.05	0.19	0	0	0.10	0.16	0.09	0.24	0.29	0.17	0.10
Pollack	*Pollachius pollachius*	0.13	0.12	0.15	0.07	0.24	0.65	0.23	0.10	0.15	0.22	0.19	0.09	0.20
Greater forkbeard	*Phycis blennoides*	0.01	0.04	0.02	0.05	0.06	0.12	0.05	0.18	0.22	0.2	0.07	0.11	0.11
Total		94.26	49.23	33.09	30.04	164.23	41.18	34.48	66.96	46.16	54.74	35.16	89.64	61.32
Total (except saithe and roundnose grenadier)		21.34	20.65	20.58	19.95	49.46	24.15	24.46	55.84	31.12	46.87	29.75	82.66	53.43

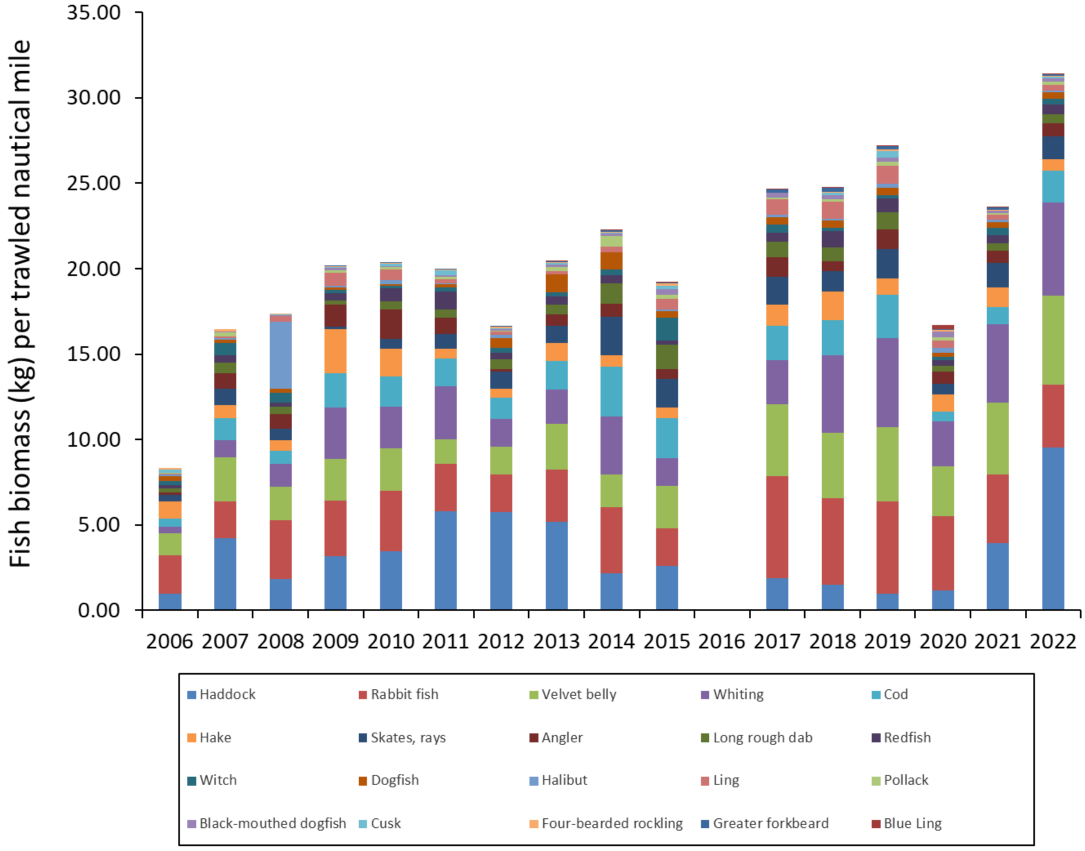

Figure 1.2. Northern shrimp in Skagerrak and Norwegian Deep: Estimated indices of predator biomass (catch in t per square nautical mile) from the Norwegian shrimp survey in 2006–2022 excluding saithe, roundnose grenadier and blue whiting. The 2016 survey data have been omitted (see text for details).

1.2 Input data

1.2.1 Fishery data

Commercial landings data for *Pandalus* are available (to NIPAG), and used in the assessment, from 1970 to present day. Landings are reported as total landed weight from each of the three countries (Denmark, Norway, and Sweden) spilt by area, quarter, and fleet. In the stock assessment, landings are inputted to the model for all years until 2007, while total catches, split into landings and discards, are used after 2008 for Sweden, 2009 for Norway, and 2013 for Denmark.

Danish, Swedish, and Norwegian catch and effort data from logbooks were standardised (SCR Doc. 16/056). All three LPUE series increased from 2012 until 2015, then decreased until 2018–2019, but increased again in 2020 (Figure 1.3). The Norwegian and Danish LPUE series both decreased in 2021. The trends in the LPUE time-series (Figure 1.3) follow the trend in the survey biomass index from Skagerrak (Figure 1.5).

The time-series of standardised effort from Norway has been fluctuating without any clear trend since 2000, while the Swedish and Danish effort has decreased (Figure 1.4). LPUEs by country are currently not used in the assessment.

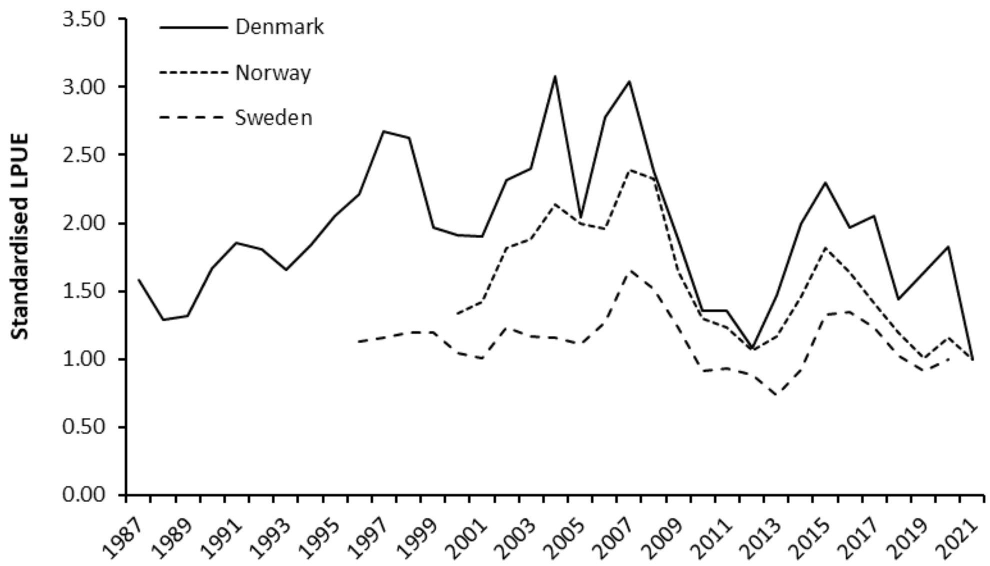

Figure 1.3. Northern shrimp in Skagerrak and Norwegian Deep: Danish, Norwegian, and Swedish standardised landings per unit of effort (LPUE) until 2021. Each series is standardised to its final year. The Swedish time series was not updated in 2022.

Figure 1.4. Northern shrimp in Skagerrak and Norwegian Deep: Estimated standardised effort until 2021. Each series is standardised to its final year. The Swedish time-series was not updated in 2022.

1.2.2 Sampling of catches

Length frequency distributions (LFDs) from commercial catches have been obtained by sampling and are provided to the assessment. LFDs are sampled from either sorted catches (split into landings and discards), landings, or unsorted (total catch) catches based on data availability. Sorted LFDs are available from the Swedish and Danish fisheries (from on-board sampling) from 2016 and 2013, respectively. In years prior, Swedish LFDs are based on samples from landings (1990-2007) or unsorted catches (2008-2015). Danish LFDs (as unsorted catches) before 2013 are available (2009-2012) but are not currently included in the assessment.

Since 2006, LFDs from unsorted Norwegian catches have been obtained through self-sampling by fishermen and from the Norwegian Coast Guard's inspections of the fishing fleet. Since 2017, LFDs from sorted catches have been obtained from the shrimp trawlers in the Norwegian Coastal Reference fleet. LFDs from both unsorted (2006-2020) and sorted (2017-2021) Norwegian catches are used in the assessment.

Estimated total discards, based on on-board sampling, are also available and provided to the assessment. Estimated discards are available from Sweden since 2008 and from Denmark since 2013. Until 2015, no Norwegian observer data exist. However, in 2016 Norway initiated a sampling program (the Coastal Reference Fleet) within which a selected number of shrimp vessels report all catches (including all discards). Since 2017 (too little data in 2016), Norwegian discard estimates are based on data from the Coastal Reference fleet.

For 2009–2016, Norwegian discards of *Pandalus* in the Skagerrak are estimated by applying the Danish discards-to-landings ratio to the Norwegian landings. These estimated discards in the Skagerrak are likely to provide an underestimation, as the proportion of boiled shrimp in the Norwegian landings is larger than in the Danish landings. As there is minimal Danish observer data from the Norwegian Deep, there are no estimates of Norwegian discards from this area for 2009-2016.

Total discards and LFDs are spilt by area, year, quarter, and fleet. LFDs also provide information on sex distribution and maturity

1.2.3 Survey data

Two survey indices from the Norwegian shrimp survey are provided to the assessment. These indices are total biomass by year and area, and LFDs by year, area, and sex.

Until 2021, a design-based survey index was used as input to the assessment, whereby abundance-at-length was calculated as the mean density raised to the corresponding area and depth stratum within the survey strata system. Inconsistencies within the time series in coverage due to weather and technical issues required ad hoc corrections for missing strata and resulted in the removal of the entire 2016 survey from the previous survey index (due to unequal wire lengths of the trawl gear). In addition, the design-based approach was found to be sensitive to a stratified design due to the narrowness of the depth contours, as well as start- and stop-locations of trawl stations that sometimes cross strata or area borders.

Model-based survey standardizations that combine fixed effects (e.g., bottom depth) with random effects, and include information on spatio-temporal correlation have been shown to resolve issues such as those described above. The model described in Breivik *et al.* (2021) was specifically developed with the goal of improving the prediction of abundance-at-length data using spatial random fields and correlation between length groups. Consequently, the model of Breivik et al. (2021) was implemented to support the assessment of the stock and was agreed upon at the 2022 benchmark (ICES, 2022).

The model was fit to abundance-at-length data from the most recent section of the survey time series (2006-current year, see below). The expected abundance-at-length is modelled as a Poisson distribution, with a length- and year-dependent intercept, a non-linear depth effect, a latent mean zero Gaussian random haul effect with correlation structure across length within hauls, and spatio-temporal-length mean zero Gaussian random effects, as well as trawl distance as an offset. Length-dependent intercepts are linked through time using a random walk process to improve the estimation of rarely observed length groups. The correlation structures of the spatio-temporal random effects are further assumed to be stationary in space and with separate first order auto regressive (AR1) structures in both time and length. The latent haul effect accounts for an unexplained variation within each haul and includes an AR1 correlation structure in length. Only hauls located within the strata system are considered, and every three subsequent length groups are linked together for the estimation of latent effects to reduce the number of parameters and computational requirements. The spatial mesh was built using the triangulation method provided by R-INLA, using a minimum allowed distance between points of 30 km. Sensitivity tests showed that the selected configuration and mesh resolution were robust and provided an adequate balance between sufficient model complexity, stability and running time.

In addition to the LFD index, the assessment also considers a total biomass index. To ensure consistency in the methods used, total biomass is estimated using a spatio-temporal model implemented in sdmTMB package. This model mimics the model setup and configuration used for the LFD index with total observed density (catch weight per nautical square mile) as the response variable, as opposed to abundance-at-length. Comparing the split estimates of the old/new survey data (1984-2005, and 2006-present) with an estimate that uses the joint time-series (1984-present) showed that a joint biomass index is preferable. This is because the mean estimates are very similar, however, the longer time series aids the parameter estimation and results in lower uncertainty especially in the new time series.

Total biomass and associated uncertainty are predicted by area (Skagerrak and the Norwegian Deep). The resulting index follows largely the same trend as the design-based estimate with some notable deviations, particularly in years with coverage issues. Data from the 2016 survey are not included in the log-likelihood estimation and, thus, have no influence on the overall parameter estimates. However, abundance-at-length and uncertainty for 2016 are predicted from the model using the estimated fixed effects (bottom depth) and correlation structure. In contrast to the design-based index, the model-based approach enables the estimation of an index for 2016 that adequately reflects the associated uncertainty and, thus, provides better information of the abundance in 2016 than excluding the year entirely.

The stock indices for the two earlier time-series (numbers-at-length), 1984-2002 and 2004-2005, are still design-based indices and are estimated in the software StoX (Johnsen *et al.*, 2019). Survey coverage was less of an issue when the survey was carried out in October/November, but in 2002, the northernmost stratum H1 was not covered.

The Norwegian shrimp survey went through large changes in vessel, gear, and timing in 2002–2006, resulting in four indices: Survey 1: October/November 1984–2002 with Campelen trawl; Survey 2: October/November 2003 with shrimp trawl 1420; Survey 3: May/June 2004–2005 with Campelen trawl; and Survey 4: January/February 2006–present with Campelen trawl.

In the Norwegian Deep, biomass peaked in 2003-2004, then declined until 2012. The increase in biomass in 2014 is due to the large 2013-year class. During the last six years the index has fluctuated at a low level without any clear trend (Figure 1.5). In Skagerrak, biomass peaked in 2007. The small peak in 2014-2015 is attributed to the large 2013-year class. As in the Norwegian Deep, the index has fluctuated around a low level for the last six years.

A recruitment index has been calculated for the fourth survey time-series as the abundance of age 1 shrimp. The recruitment index declined from 2007 to 2010, and has since fluctuated at a lower level except for a peak in 2014 (Figure 1.6). The 2021 year class is estimated to be a good year class.

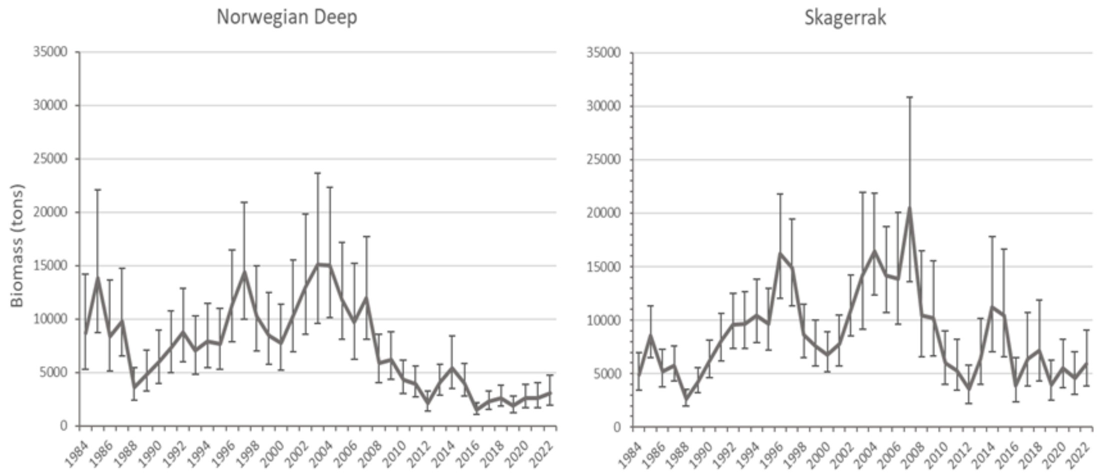

Figure 1.5. Northern shrimp in Skagerrak and Norwegian Deep: Modelled survey biomass index per area in 1984–2022, with confidence intervals.

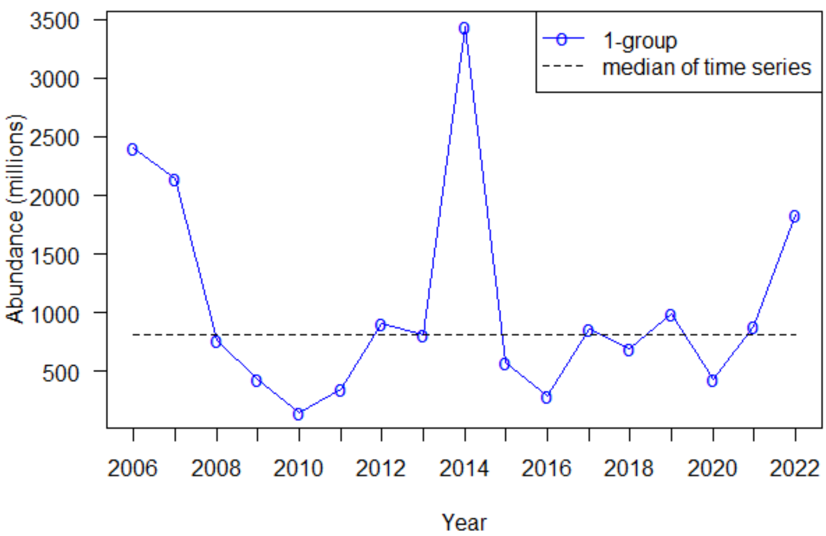

Figure 1.6. Northern shrimp in Skagerrak and Norwegian Deep: Estimated recruitment index, 2006–2022. The horizontal line is the median of the time-series. The 2016 survey data have been omitted (see text for details).

1.2.4 Model

The stock assessment was benchmarked in January 2022 (ICES, 2022). At the benchmark, it was decided that a length-based Stock Synthesis (SS3) statistical framework would still be used for the assessment of the stock, but that the model would be updated in several ways (ICES, 2022, and references therein). The updated model still has a quarterly time step, but contrary to the old model it is split into two areas and considers six fleets (split by area and country), with a population comprising of 8+ age classes (with age 8 representing a plus group). The updated model also incorporates hermaphrodism whereby individuals are born as males but change sex to females at approximatively age 2.

A novel approach to fitting the model is also used. This approach involves running three different SS3 models with differing natural mortality rates. These three models are then assigned weights based on model diagnostics and combined in an ensemble model that provides the final assessment of the stock. During the benchmark, new reference points were also defined and are described below (ICES, 2022).

1.2.5 Assessment results

SS3 model diagnostics of this year's assessment do not indicate any issues with the model fit. There is a positive retrospective pattern in SSB and a negative retrospective pattern in F and recruitment, but the patterns are within the acceptable range of requiring no action.

Note, model diagnostics are presented from model one (of three), where age-varying natural mortality is assumed to be at the median rate (see ICES, 2022 for more details).

1.2.6 Sensitivity analysis

Prior to the assessment meeting, some small changes to the input data used at the benchmark were made by the assessment team. These changes, by country, are as follows:

Sweden. Addition of discard data for Q1 in 2017 and update to LFDs from 2016-2021. The discard estimate in Q1 in area 3.a in 2017 was updated from 0 (i.e. no data) to 25.2 tonnes. The LFDs were corrected to account for an error in the rounding of abundance-at-length data.

Denmark. Small correction to the sample numbers (number of trips) for DK LFDs for 2018-2020.

To access what effect, if any, these small changes had on the assessment model, a sensitivity analysis was conducted whereby model one was run with and without each change. These two runs were then compared graphically. An end year of 2020 was used so that run without change was equivalent to the benchmark run (ICES, 2022).

As shown in figures 1.7 and 1.8, the small data changes had minimal impact on estimates of SSB, F and recruitment. The only observable change occurs in the estimate of F in 2017 in Figure 1.7 and this can be linked directly to addition of Swedish discards in Q1 in 3.a. Consequently, the updated data for SWE and DK was used in the assessment.

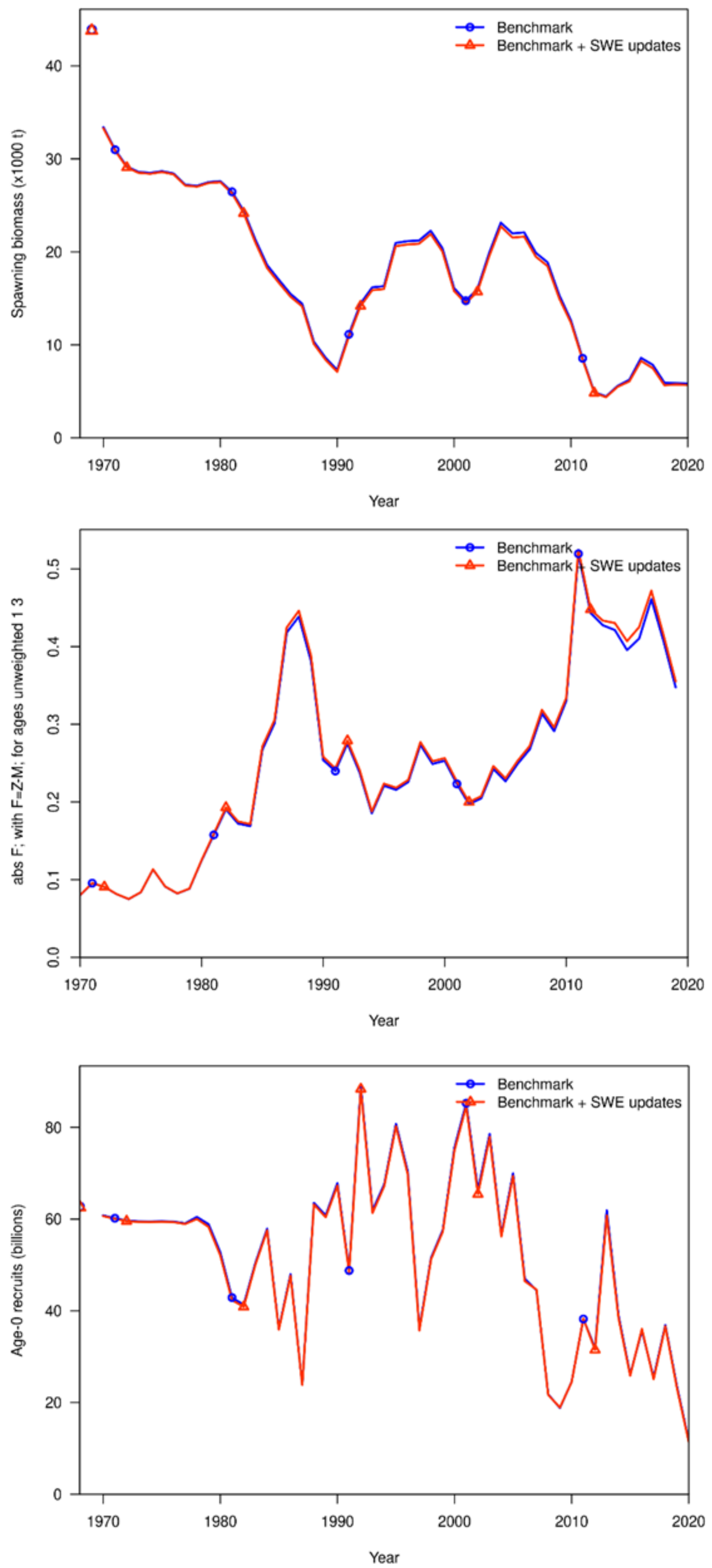

Figure 1.7. Northern shrimp in Skagerrak and Norwegian Deep: SSB, F and recruitment estimates from the assessment model with (red) and without (blue) Swedish data changes. Age-varying naturality mortality is set at the median rate (ICES, 2022).

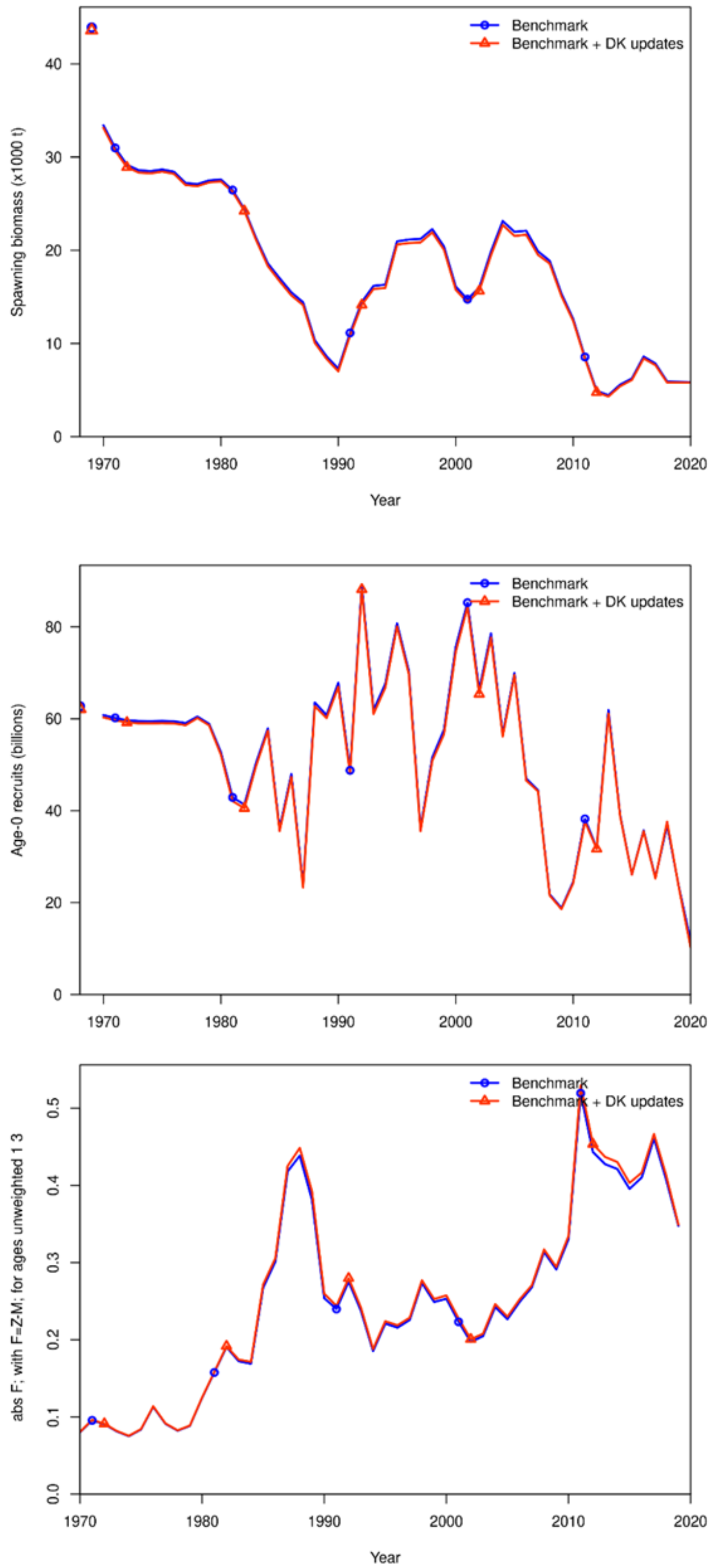

Figure 1.8. Northern shrimp in Skagerrak and Norwegian Deep: SSB, F and recruitment estimates from the assessment model with (red) and without (blue) Danish data changes. Age-varying naturality mortality is set at the median rate (ICES, 2022).

1.2.7 Historical stock trends and recruitment

Historical stock trends are shown in Figure 1.9.

Since 2010, when the SSB of mature females exceeded MSY $B_{trigger}$, SSB/MSY $B_{trigger}$ has decreased and stayed below 1 and close to B_{lim}. In general, the SSB relative to MSY $B_{trigger}$ has been around 0.4-0.6 for the last 11 years.

SS3 models recruitment as the abundance of the 0-group. A series of low recruitment years since 2008, with the exception of 2013 and 2021, should be noted. During this period of low recruitment, the estimates of SSB/MSY $B_{trigger}$ were also, for some years, historically low and close to or below B_{lim}. The estimated recruitment for 2021 is one of the largest on record, however, the uncertainty around this estimate is also large. The reason for this is that the model has only observed the recruits in the survey data once (collected with a smaller meshed survey trawl in January the terminal year +1) and gains no information on recruits in the commercial catch data (catch data are until and including the terminal year).

Fishing mortality (F) relative to F_{MSY} remained relatively stable from the beginning of the 1990s to 2007. After 2007, F/F_{MSY} increased steeply to 1.31 in 2011, which is the highest observed value in the time-series. F has been estimated above F_{MSY} in all years since 2011, except in 2019 and 2021. The estimated F relative to F_{MSY} in 2021 is 0.93.

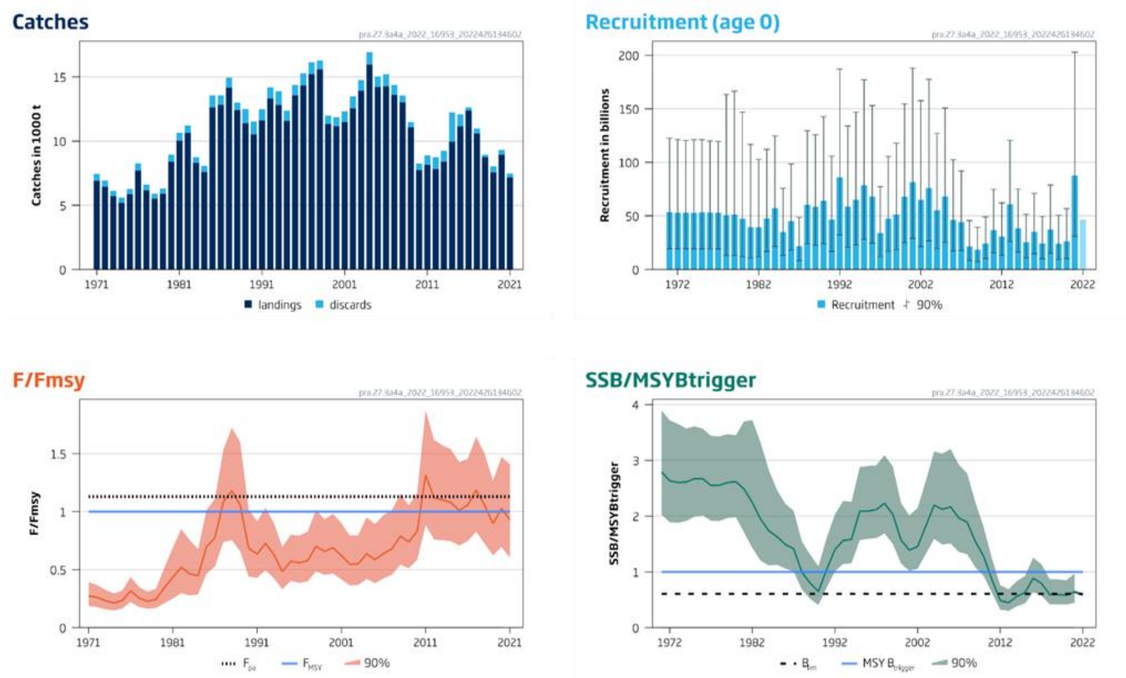

Figure 1.9. Northern shrimp in Skagerrak and Norwegian Deep: Summary of the stock assessment. Assumed recruitment is shown in a lighter shade of blue. Note: B_{pa} = MSY $B_{trigger}$. SSb is the biomass of mature females.

As part of the 2022 benchmark (ICES, 2022), landings data split by area and quarter back to 1908 (Sweden and Norway) and 1940 (Denmark) was compiled and digitised. These historic catches (1908-1969) were not used in the assessment of the stock, however, an exploratory run of model 1 (median M) was conducted using the full time series (1908-2022) and can be used to visualise the development of the stock through time (Figure 1.10). The SSB has declined notable over the last century and is currently estimated to be at 13.2% of the SSB in 1908.

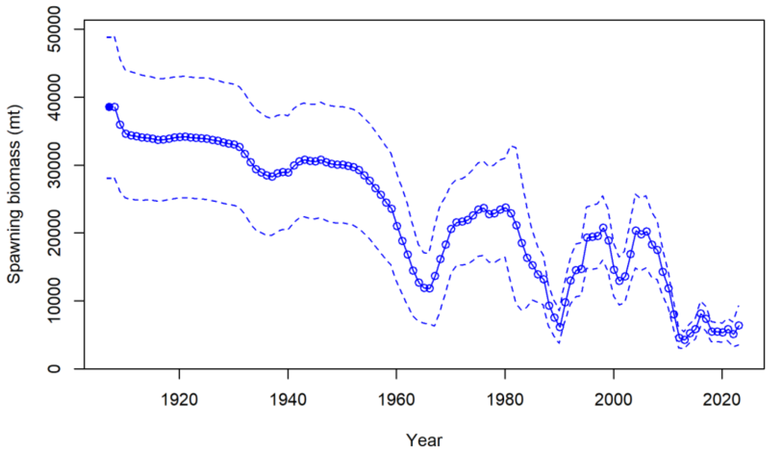

Figure 1.10. Northern shrimp in Skagerrak and Norwegian Deep: Estimated SSB of mature females from 1908 to 2022.

1.2.8 Model retrospective

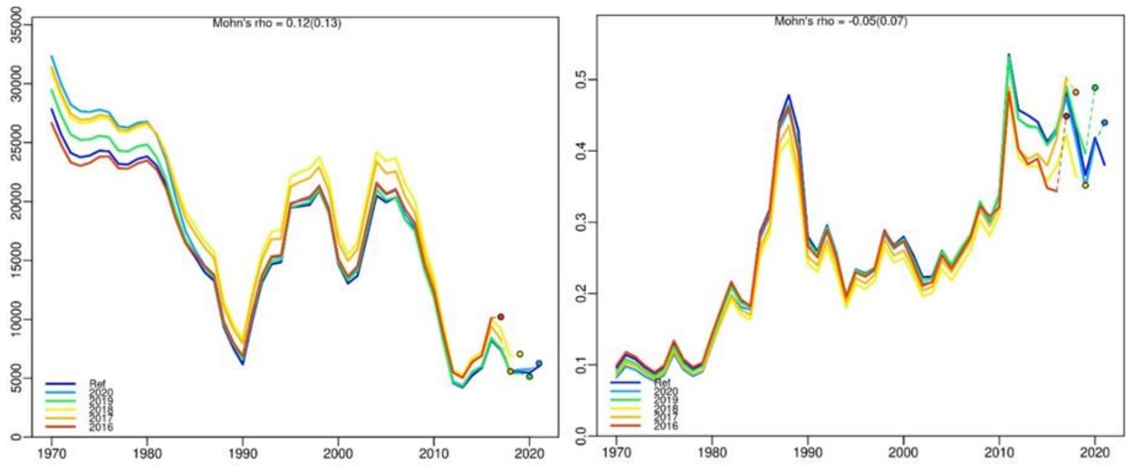

Figure 1.11. Northern shrimp in Skagerrak and Norwegian Deep: Model retrospective for SSB (left) and F (right). Here, F is presented as an average weighted by the number of shrimps in the age classes of F_{bar} ages 1 to 3. Mohn's rho estimates are stated.

Model retrospectives for the assessment are shown in Figure 1.11. There is a negligible retrospective pattern for the more recent part of the time-series of SSB, with a tendency to overestimate SSB. There is also a small tendency to underestimate F. In both cases, estimates of Mohn's rho are within the acceptable range of requiring no action.

Recruitment is somewhat underestimated by the model with a Mohn's rho value of -0.20 (Figure 1.12), meaning that the previous year classes have been revised upwards.

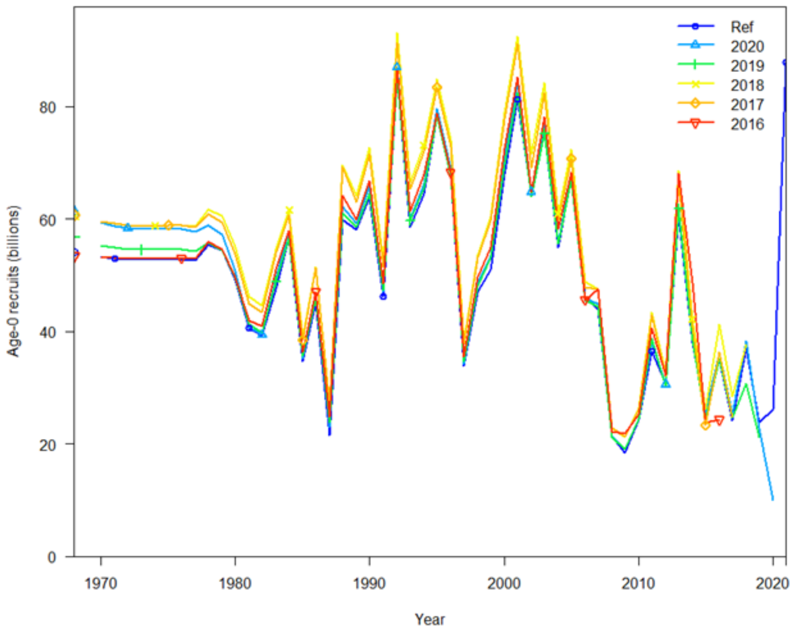

Figure 1.12. Northern shrimp in Skagerrak and Norwegian Deep: Model retrospective for recruits.

Retrospective patterns in the estimation of recruitment deviations are shown in Figure 1.13. Previous assessments of this stock have shown that two years of observing a cohort is necessary to estimate it with low uncertainty (ICES, 2021). This does not necessarily apply to the new ensemble model with recruitment deviations appearing very stable during the historical period. Continued use of the ensemble model will enable a quantification of the accuracy of its recruitment estimates.

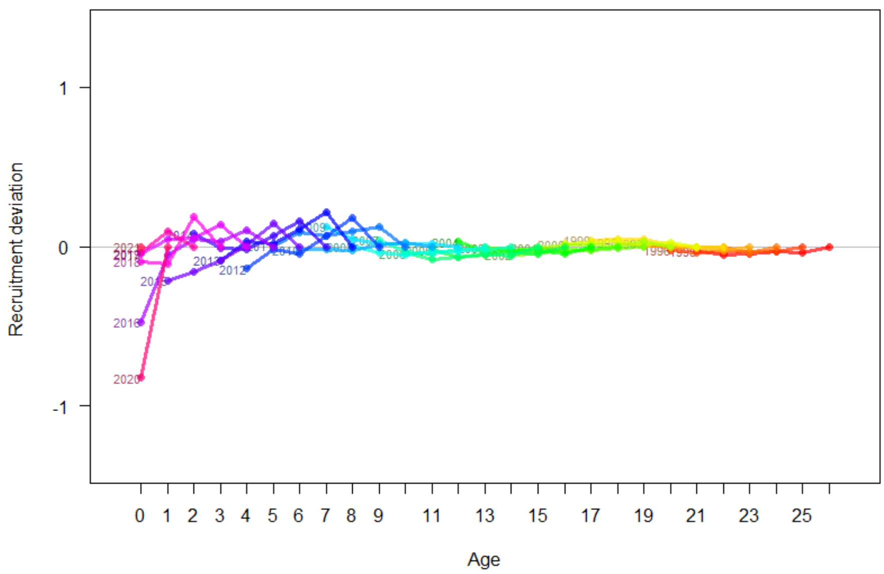

Figure 1.13. Northern shrimp in Skagerrak and Norwegian Deep: Model retrospective patterns in the estimation of recruitment deviations.

1.3 Long-term management strategy

In April 2018 following an ICES management strategy evaluation (ICES, 2017a), a long-term management strategy (LTMS) was agreed between EU and Norway (Anon, 2018). The LTMS is detailed below. However, as the stock was benchmarked in 2022 and new reference points were computed, the advice was based on these new reference points (See section 1.4 below) and not the F_{TARGET} and B_{MGT} specified in the LTMS. Other parts of the LTMS still hold.

Values for B_{MGT} ($B_{TRIGGER}$) and F_{TARGET} are fixed at levels of 9900 t and 0.59, respectively and the TAC will be established for each calendar year (from January 1st to December 31st).

- *By end of the year N-1, a preliminary TAC will be adopted by the Parties based on ICES catch forecast for the six first months of the year N, released in March of year N-1.*
- *The Parties will establish the final TAC for the entire year N in light of the ICES catch advice released in March of year N.*

When establishing the preliminary and the final TACs the following rules shall apply:

a) When the SSB at the start of the year is estimated at or above B_{MGT} the Parties will fix a TAC consistent with a fishing mortality rate of F_{TARGET}.

b) When the SSB at the start of the year is estimated below B_{MGT}, the Parties will fix a TAC consistent with a fishing mortality rate of F_{TARGET} x (SSB/B_{MGT}).

The TAC will include all removals made from the stock.

When SSB is estimated to be at or above B_{MGT}, the TAC derived from paragraph (a) can be deviated with up to 10% according to the agreed "banking and borrowing" scheme described in Annex III of the agreed record (Anon., 2018).

The LTMS will be applicable from 1st of January 2019 onwards.

The management strategy shall be revised by the end of 2021 or following the next ICES benchmark of the stock.

The advised TAC for the first two quarters of year N is based on multiplying the full TAC from the short-term forecast for year N with the average proportion of quarterly catches ([Q1+Q2]/[Q1+Q2+Q3+Q4]) from the previous five years.

When the EU and Norway LTMS is fully implemented in 2019, it will rely on annual ICES advice issued in March. In the current transition phase, the clients have requested ICES to issue an advice for the first two quarters of 2019, based on the LTMS, in October 2018.

1.4 Reference points

New reference points were computed at the benchmark in January 2022 and were used to provide advice for 2022 and 2023 (ICES, 2022).

In 2009, ICES adopted a "Maximal Sustainable Yield (MSY) framework" (ACOM. ICES Advice, 2017b. Book 1. Section 1.2) for deriving advice. It considers two reference points: F_{MSY} and MSY $B_{trigger}$. (Table 1.4). Under the ICES PA, two reference points are also required: B_{lim} and B_{pa} (Table 1.4). In previous assessments (e.g. ICES 2016; ICES 2021), B_{loss} was used to derive B_{lim}, however, in the ensemble model, B_{loss} will be inherently different for the different model configurations and therefore a fraction of B_0 was used (ICES, 2022). For *Pandalus*, B_{lim} was set at 15% of B_0, which is approximately the average B_{loss} for the three SS3 models in the ensemble (B_{loss} range: 11-17% of B_0).

A MSE 'short-cut' approach was used to determine new target and trigger reference points (ICES, 2022). The MSE simulations were run for all three models in the ensemble and resulted in an update in the values of MSY Btrigger, F_{MSY} and F_{pa}. At the benchmark, the group agreed that a combination of an F_{MSY} proxy at $F_{B30\%}$, combined with $B_{trigger}$ at 80% of $B_{30\%}$ satisfied the ICES criterion of being above B_{lim} with 95% probability whilst generating the highest possible catches (in this case corresponding >97% of the deterministic MSY). F_{pa} was estimated at 1.13*F_{MSY} and B_{pa} is estimated to be equal to MSY $B_{trigger}$.

It is worth noting that the new reference points are all relative values and should be interpreted with that in mind.

Table 1.4. Northern shrimp in Skagerrak and Norwegian Deep: Reference points, values, and their technical basis.

Framework	Reference point	Value*	Technical basis	Source
MSY approach	MSY $B_{trigger}$	$0.8 \times B_{30\%}$	Relative value. Set at 80% of $B_0 \times 30\%$ (B_{MSY}). Determined through management strategy evaluation with the objective to achieve high sustainable yields without exceeding a 5% probability of SSB falling below B_{lim} in any single year.	ICES 2022
	F_{MSY}	$F_{B30\%}$	Relative value. Set as the F which will achieve $B_0 \times 30\%$ (B_{MSY}). Determined through management strategy evaluation with the objective to achieve high sustainable yields without exceeding a 5% probability of SSB falling below B_{lim} in any single year.	ICES 2022
Precautionary approach	B_{lim}	$0.15 \times B_0$	Relative value. Set at 15% of B_0, which is approximately the average B_{loss} for the three models in the ensemble.	ICES 2022
	B_{pa} MSY $B_{trigger}$	$0.8 \times B_{30\%}$	Relative value. Set at 80% of $B_0 \times 30\%$ (B_{MSY}). Determined through management strategy evaluation with the objective to achieve high sustainable yields without exceeding a 5% probability of SSB falling below B_{lim} in any single year.	ICES 2022
	F_{pa}	$1.13 \times F_{MSY}$	$F_{p0.5}$. Relative value. The F that leads to SSB ≥ B_{lim} with 95% probability.	ICES 2022
Management plan	B_{mgt}			
	F_{mgt}			

***Fishing mortality is presented only in relation to F_{MSY} and total stock biomass is presented only in relation to B_{MSY}. These values are directly estimated from the stock assessment and change when the assessment is updated.**

1.4.1 Catch scenarios

In accordance with the requirements of the LTMS, two sets of catch scenarios were provided; i) updated catch scenarios for the full year 2022 and ii) catch scenarios for the first semester (Q1 and Q2) of 2023.

Table 1.5. Northern shrimp in Skagerrak and Norwegian Deep: The basis for the updated catch scenarios for 2022.

Variable	Value	Notes
F_{2021*}/F_{MSY}	0.921	From the assessment. Relative value.
SSB_{2022}/MSY $B_{trigger}$	0.60	From the assessment. Relative value.
R_{2022}	46.61	Estimated from the model, in billions
* $F_{2021}=F_{MSY} \times (SSB_{2021}$/ MSY $B_{trigger})$		

Given the new 2022 datapoint for the survey time-series and an estimated catch of 7484 tonnes in 2021, updated catch scenarios were provided for 2022 (Table 1.6). The advised TAC for 2022 is 7712 tonnes (the basis for the two updated catch scenarios is provided in Tables 1.5 and 1.7).

Table 1.6. Northern shrimp in Skagerrak and Norwegian Deep: Updated catch scenarios for 2022.

Basis	Total catch (2022)	F_{total} (2022)/F_{MSY}	Stock Size (2023)/$B_{trigger}$	% Probability of SSB (2023) >B_{lim}	% Probability of SSB (2023) >$B_{trigger}$	% SSB change *	% TAC change **	% Advice change ***
MSY approach F = F_{MSY} * (SSB_{2022}/ MSY $B_{trigger}$)	7712	0.60	0.79	84.87	14.50	31.7	7.62	7.62
Other scenarios								
F = 0	0	0	1.04	99.67	58.60	73.3	-100	-100
F_{pa}	13475	1.13	0.61	46.81	3.01	1.7	88.04	88.04
F_{2021}	11454	0.93	0.67	61.18	4.83	11.7	59.84	59.84
$SSB_{2023} = B_{lim}$	13177	1.10	0.63	50.68	3.15	5.0	83.88	83.88
$SSB_{2023} = B_{pa} = B_{trigger}$	1120	0.08	1.00	99.31	50.43	66.7	-84.37	-84.37

*** SSB_{2023}/ MSY $B_{trigger}$ relative to predicted SSB_{2022}/ MSY $B_{trigger}$.**

**** Advised catch in 2022 relative to TACs in 2021 (7166 tonnes).**

***** Advised catch in 2022 relative to advised catch in 2021 (7166 tonnes).**

The stock was benchmarked in 2022 which resulted in a new assessment model, new reference points, and a changed perception of the stock. The stock estimates are therefore not directly comparable to the assessment in 2021. Consequently, the reasons for the reduction in the advised catch for 2022 relative to the catch initially advised for 2022 is not entirely known.

Table 1.7. Northern shrimp in Skagerrak and Norwegian Deep: The basis for the 1st semester catch-scenarios for 2023.

Variable	Value	Notes
F_{2022*}/F_{MSY}	0.73	Average exploitation pattern (2020–2022). Scaled to the catch advice for 2022. Relative value.
SSB_{2023}/MSY $B_{trigger}$	0.68	Short-term forecast. Relative value.
R_{2023}	39.67	Estimated from the model, in billions.
Catches 2022	7712	Catch advice for 2022, in tonnes
* $F_{2022}=F_{MSY} \times (SSB_{2022}/$ MSY $B_{trigger})$		

Table 1.8. Northern shrimp in Skagerrak and Norwegian Deep: Catch scenarios for 1st semester of 2023.

Basis	Total catch (2023)	Q1 and Q2 catch (2023) ^	F_{total} (2023)/F_{MSY}	Stock Size (2024)/$B_{trigger}$	% Probability of SSB (2024) >Blim	% Probability of SSB (2024) >Btrigger	% SSB change *	% TAC change **	% Advice change **
MSY approach F = F_{MSY} * (SSB_{2023}/ MSY $B_{trigger}$)	11646	5882	0.6764	1.33	99.42	83.84	95.6	51.01	51.01
Other scenarios									
F = 0	0	0	0	1.80	99.99	98.43	164.7	-100	-100
F_{pa}	17814	8997	1.13	1.05	93.21	56.84	54.4	130.99	130.99
F_{2022}	12186	6155	0.71	1.31	99.17	81.14	92.6	58.01	58.01
$SSB_{2024} = B_{lim}$	27765	14023	2.08	0.67	55.40	20.74	-1.5	260.02	260.02
$SSB_{2024} = B_{pa} = B_{trigger}$	19280	9738	1.25	0.99	83.53	49.08	45.6	150.00	150.00

*** SSB_{2024}/MSY $B_{trigger}$ relative to predicted SSB_{2023}/MSY $B_{trigger}$.**

**** Advised catch in 2023 relative to advised catch in 2022 (7712 tonnes).**

^ Total catch in 2023 x average proportion of catch taken in the first six months of each of the last 5 years (2017-2021; 0.505)

The initial catch advice for 2023 (Table 1.8) is 51% larger than the advised catch for 2022 mainly because the 2021- and the projected 2022-year classes are estimated to be larger than the 2020-year class. These large year classes result in a higher stock biomass and a higher advised fishing mortality for 2023.

1.5 State of the stock

Mortality. F has been above F_{MSY} in all years since 2011, except in 2019 and 2021. F in 2021 is 0.93.

Biomass. The spawning–stock biomass of mature females (SSB) declined after 2010 and has fluctuated at a level below MSY $B_{trigger}$ since then.

Recruitment. Recruitment has been below the long-term average since 2008, except for the 2013-year class. Recruitment in 2021 is expected to be large.

State of the Stock. Fishing pressure on the stock is close to F_{MSY} and spawning–stock size is below MSY $B_{trigger}$ and B_{pa} but above B_{lim}.

Yield. According to the MSY approach, catches in 2022 should be no more than 7712 tonnes and in the two first quarters of 2023 no more than 5882 tonnes.

1.6 Research recommendations

NIPAG **recommended** in 2010–2014 that differences in recruitment and stock abundance between Skagerrak and the Norwegian Deep should be explored.

Status: This issue was addressed at the 2022 benchmark (ICES, 2022). The new assessment model contains two areas and therefore accounts for differences in recruitment and stock abundance between Skagerrak and the Norwegian Deep.

NIPAG **recommended** in 2016 that a full benchmark for this stock, including a data compilation workshop, be conducted in the near future and no later than 2020.

Status: A benchmark took place in January 2022 and resulted in a new assessment model and with new reference points.

WKPRAWN **recommended** in 2022 that live weight conversion factors and raising procedures should be investigated by time, country, and conservation type (i.e., boiled air cooled, boiled water cooled, and iced, for different durations and even frozen).

Status: Investigations in Sweden, Denmark and Norway are ongoing and will be presented at the next NIPAG meeting. This work should also be coordinated with WGCATCH.

WKPRAWN **recommended** in 2022 that changes in growth or differences in growth across time and area should be investigated. This recommendation was made based on observed patterns in the model's residuals.

Status: Differences in growth across time and area are not currently accounted for in the model. Investigations are needed to explore what differences exist and how they might be best included in the assessment. This work should be conducted prior to the next benchmark.

WKPRAWN **recommended** in 2022 that a time varying predation index could be utilised as a fourth scenario for M in the model.

Status: This work is ongoing and preliminary work was presented at the 2022 benchmark (ICES, 2022). Further work on the evaluation of model uncertainty and model fit, as well as decisions on the composition of predators is needed before the approach can be implemented in the assessment.

2 References

Anon. 2018. Agreed Record of Fisheries Consultations between the European Union and Norway for 2018. 25. April 2018.

Breivik, O. N., Aanes, F., Søvik, G., Aglen, A., Mehl, S. and Johnsen, E. 2021. Predicting abundance indices in areas without coverage with a latent spatio-temporal Gaussian model. ICES Journal of Marine Science. doi:10.1093/icesjms/fsab073

Hatlebrekke, H.H., Gundersen, S., Nedreaas, K., Vølstad, J.H. and Kolding, J. 2021. The Coastal Reference Fleet 2007-2019. Fleet composition, fishing effort and contributions to science. Rapport fra Havforskningen 2021-52. ISSN:1893-4536. 61 pp.

ICES. 2016. Report of the Benchmark Workshop on Pandalus borealis in Skagerrak and Norwegian Deep Sea (WKPAND), 20–22 January 2016, Bergen, Norway. ICES CM 2016/ACOM:39. 72 pp.

ICES. 2017a. Report on the Long-term Management Strategy Evaluation for Northern Shrimp (Pandalus borealis) in Division 4.a East and Subdivision 20 (PandLTMS). October–November 2017, ICES CM 2017/ACOM:52. 182 pp.

ICES. 2017b. ICES fisheries management reference points for category 1 and 2 stocks. In Report of the ICES Advisory Committee, 2017. ICES Advice 2017 Technical Guidelines, Book 12, 12.4.3.1, DOI: 10.17895/ices.pub.3036.

ICES. 2021. Joint NAFO\ICES Pandalus Assessment Working Group (NIPAG). ICES Scientific Reports. 3:22. 25 pp. https://doi.org/10.17895/ices.pub.5990.

ICES. 2022a. Benchmark workshop on Pandalus stocks (WKPRAWN). ICES Scientific Reports. 4:20. 249 pp. http://doi.org/10.17895/ices.pub.19714204

Johnsen, E., Totland, A., Skålevik, Å., Holmin, A.J., Dingsør, G.E., Fuglebakk, E. and Handegard, N.O. 2019. StoX: An open source software for marine survey analyses. Methods in Ecology and Evolution 10: 1523-1528. DOI: 10.1111/2041-210X.13250

Munch-Petersen, S., Ulmestrand, M., Søvik, G. and Eigaard, O. 2013. Discarding in the shrimp fisheries in Skagerrak and the Norwegian Deep (ICES Divisions IIIa and IVa East). NAFO SCR Doc. 13/068. 9 pp.

Søvik, G., Zimmermann, F. and Thangstad, T. 2022. Results of the Norwegian Bottom Trawl Survey for Northern Shrimp (Pandalus borealis) in Skagerrak and the Norwegian Deep (ICES Divisions 3.a and 4.a east) in 2022. NAFO SCR Doc. 22/001, Serial No. N7263.

Ulmestrand, M., Bergenius, M., Eigaard, O., Søvik, G., and Munch-Petersen, S. 2016. The Northern shrimp (Pandalus borealis) Stock in Skagerrak and the Norwegian Deep (ICES Divisions IIIa and IVa East). NAFO SCR Doc. 16/056

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Annex 2: Stock Annex for Northern shrimp (*Pandalus borealis*) in Division 4.a East and Subdivision 20 (northern North Sea in the Norwegian Deep and Skagerrak)

Stock ID	Stock name	Last updated	Link
Northern shrimp (*Pandalus borealis*) in Division 4.a East and Subdivision 20 (northern North Sea in the Norwegian Deep and Skagerrak)	*Pandalus borealis*	March 2022	Pand_SA